A Decision System for Routing Returned Product to the Optimal Recovery Channel

By Christopher C. Lin

B.S. Biomedical Computation, Stanford University, 2005

Submitted to the MIT Sloan School of Management and the Department of Electrical Engineering and Computer Science in Partial Fulfillment of the Requirements for the Degrees of

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Signature of Author ______________________________
May 7, 2010
Electrical Engineering and Computer Science
MIT Sloan School of Management

Certified by ______________________________
David Simchi-Levi, Thesis Supervisor
Professor of Civil and Environmental Engineering and Engineering Systems

Certified by ______________________________
Roy Welsch, Thesis Supervisor
Professor of Statistics and Management Science, MIT Sloan School of Management

Accepted by ______________________________
Terry Orlando, Professor of Electrical Engineering and Computer Science
Chair, EECS Committee on Graduate Students

Accepted by ______________________________
Debbie Berechman, Executive Director of MBA Program
MIT Sloan School of Management

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Abstract

Dell, a leading computer manufacturer, must deal with systems returned from its customers. Historically, it has refurbished most of its returned systems for resale on its Dell Outlet website. While this has provided high net recoveries (revenue less incurred costs) compared to its peers, Dell believes there is ample opportunity in cannibalizing some returned systems for the piece parts (i.e. "teardown"). These harvested piece parts can be used to service field systems, repair refurbished systems, or directly sold to customers as spare parts. Dell is concerned about ensuring an optimal disposition of system to teardown vs. direct resale. Written as part of research internship at Dell, this paper proposes, simulates, and evaluates a decision support system to address the question of disposition. The decision engines use historical data and statistics to estimate net recoveries in resale and forecasted demand to estimate net recoveries through teardown. Linear regressions were found to have poor power in predicting overall net recoveries; however, simple heuristics were found to identify likely low recovery systems. Overall, the implementation of the decision support system will drive improved net recoveries, with savings estimated to be greater than $1 million annually.

Thesis Supervisor: David Simchi-Levi
Title: Professor of Civil and Environmental Engineering and Engineering Systems

Thesis Supervisor: Roy Welsch
Title: Professor of Statistics & Management Science, MIT Sloan School of Management

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1. Introduction

1.1. Maximizing net recovery in the reverse supply chain

Reverse Logistics – why it's important

Many companies must deal with returned products, despite their best efforts to avoid doing so. Products can be returned for a variety of reasons ranging from customer dissatisfaction, end-of-lease returns, or faulty products. Products returns are estimated to be valued at well over $100 billion in the United States alone (Blackburn et al. 2004). The group of activities including handling, transformation, and disposition of returned products is known as the reverse supply chain. Over the past 10-20 years, an increasing number of companies have recognized the importance of treating returns as a priority, both from a business and environmental perspective.

This paper introduces SORT, a tool implemented at Dell for routing returned computers to the optimal recovery channel, in order to maximize net recovery. Routing returned product is one part of the larger reverse supply chain process. Guide and Van Wassenhove propose 5 key steps in a reverse supply chain (Guide Jr. and Van Wassenhove 2002). They are:

- Product acquisition – Companies must be diligent in properly managing the quality, quantity, and timing of product returns. This requires working closely with customers, retailers, and distributors.

- Reverse logistics – Once the product is acquired, it must be transported back to the company for the remaining steps. In some cases, it may make sense for a company to outsource these operations.
- Inspection and disposition – In this step, the company must decide what to do with the returned product, often after inspecting it. Guide and Van Wassenhove suggest that in general, it is often advantageous to make the decision as early as possible. Blackburn describes this as "preponement" (as a modification of the concept of postponement in a forward supply chain). This paper focuses on the question of disposition.
- Reconditioning – For many types of products, there is a large opportunity in remanufacturing a product for resale, or harvesting components. There is large uncertainty in these processes due to the often significantly variability in the condition of the returned product.
- Distribution and sales – Finally, a reverse supply chain often ends in the sale of the refurbished product or component to the secondary market. Potential customers include new customers that previously were not in the market for a new product. Companies must often separately develop these distribution and sales channels. Some choose to outsource this process to a 3rd party specializing in secondary market sales.

Properly managing the reverse supply chain also has significant financial implications. While every industry and company is different, returns can account for as much as 10% of a company's revenues. Managing the reverse supply chain in order to retain or recover this value helps companies minimize the losses associated with these returns.

Dell's key metrics for reverse logistics

This paper presents Dell, Inc.'s approach to the reverse supply chain, and specifically identifies and presents a solution for Dell's challenge in optimally routing returned product to various recovery channels. The group responsible for product returns is the Asset Recovery Business (hereafter referred to as Dell ARB or ARB).

Dell has 3 primary strategic goals when making reverse supply chain decisions. These goals are based on interdependent metrics: reducing cycle time, maximizing net recovery, and minimizing incurred operating costs.

- *Reducing cycle time* – Processing product returns takes time. Minimizing cycle time has two primary benefits. First, it reduces inventory levels and work in progress. Second, as newer products are introduced, older computer systems lose value over time. Dell is highly incentivized to recover value from returned products as quickly as possible, due to constant product changes happening in the computer hardware industry. Blackburn (2004) and Guide (2006) discuss the time value of product returns, and illustrate how returned products lose value over time. Blackburn estimates that consumer electronic products lose an average of 1% of their value per week.
- *Minimizing operating costs* – Processing product returns takes money. Dell clearly has an interest in minimizing the amount of operating costs it puts into returned products. However, it must balance the need for low operating costs with the need to recover as much value as possible. Simply recycling these products upon receipt makes little sense, despite the lowered operational expense needed to handle the material. The need for

the balance leads to the next, and most important, metric for Dell's reverse logistics organization.

- *Maximizing net recovery* - Net recovery is an important metric for any reverse logistics organization. At Dell, net recovery is defined as total sales recovery (e.g. revenue from Dell Outlet), less incurred costs (e.g. labor and parts consumption). Much as profit incorporates the balance between revenue and sales in a traditional P&L organization, net recovery is a metric for balancing the desire for high sales recovery and low operating costs.

These metrics are all tracked by Dell's reverse supply chain group, and the goals above are the 3 components of Dell's strategy in its reverse supply chain. The scope of the project and this paper focuses on the 3rd metric listed above (maximizing net recovery).

Net recovery is the most important metric in a reverse supply chain organization because such an organization is fundamentally similar to a regular P&L organization. Just as in a traditional P&L organization, it is irrational to maximize revenue at any cost, or cut costs without consideration to the impact on revenue. Net recovery, like profit, captures the proper balance between revenue and costs. Some academic and business literature has chastised reverse logistics organizations for focusing on costs at the expense of net recovery. However, as made clear in ARB's strategy, Dell has made maximizing net recovery a strategic priority. Figure 1 visually explains the concept of net recovery.

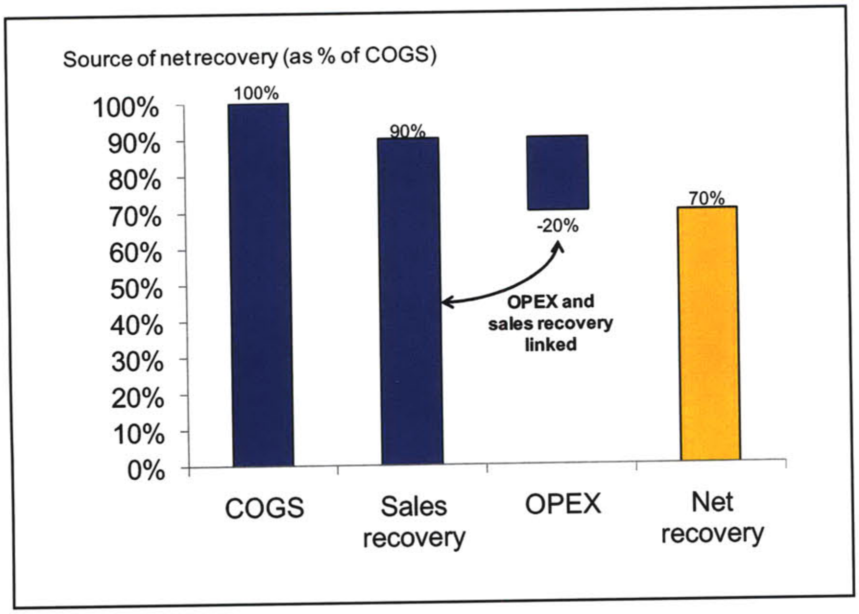

Figure 1: Explanation of net recovery metric

Once the goal of maximizing net recovery is established, many questions around operations strategy must be resolved. Beckman and Rosenfield break these questions down into structural and infrastructural decisions (Beckman and Rosenfield 2007). Structural decisions include:

- Vertical integration: Should Dell outsource reverse logistics and/or remanufacturing?
- Process technology: How automated can/should the operations be? What investments in process should be made?
- Capacity: How much capacity should Dell plan for? The reverse supply chain is unique in that the COGS (returned product) is "pushed" to the organization from its customers.
- Facilities: How many facilities should Dell have, and where should they be located?

Infrastructure decisions include:

- Sourcing: When replacement parts are needed to fix a broken computer, where do those parts come from? What amount of coordination does ARB have with the new assembly operation?
- Business processes and policies: How will ARB be organized? What are the processes for processing returns?
- Supply chain coordination: How does Dell monitor the flow of product through the returns process? How will products be routed to their final destination?
- Information technology: How much investment should be made in IT? Should IT be developed internally or externally?
- Capabilities development: How will a lean reverse supply chain be developed?

The answers to these questions formulate an operations strategy. The project described here focuses on supply chain coordination.

1.2. New recovery channels create challenges in optimal disposition

This paper focuses on the challenges of optimal disposition of returned product in order to maximize net recovery. This section begins by outlining Dell's current process flow for its outlet recovery channel, through which nearly all returned systems currently go. Next, new recovery channels (specifically teardown) are discussed. Finally, the specific challenges and questions that this project addresses are presented.

Current process flow

Currently, Dell attempts to refurbish (as necessary) nearly all returned systems and place them for sale on Dell Outlet (www.delloutlet.com). Dell Outlet is a separate part of Dell's traditional business and very different from the made-to-order model of Dell's regular direct sale. Product available for sale on Dell Outlet is already fully functional in finished goods; customers can only order what is in stock.

In order for product to arrive in Dell Outlet's finished goods inventory, processing costs must be incurred. For all product being returned from the United States, this processing currently occurs in the greater Nashville, TN area. A high level overview of the refurbishment process is provided in Figure 2. This process is provided as a more specific version of the 5 step reverse supply chain process described above. Note that Dell makes heavy use of GENCO, a 3rd party logistics partner (3PL). Figure 2 visually describes the process flow.

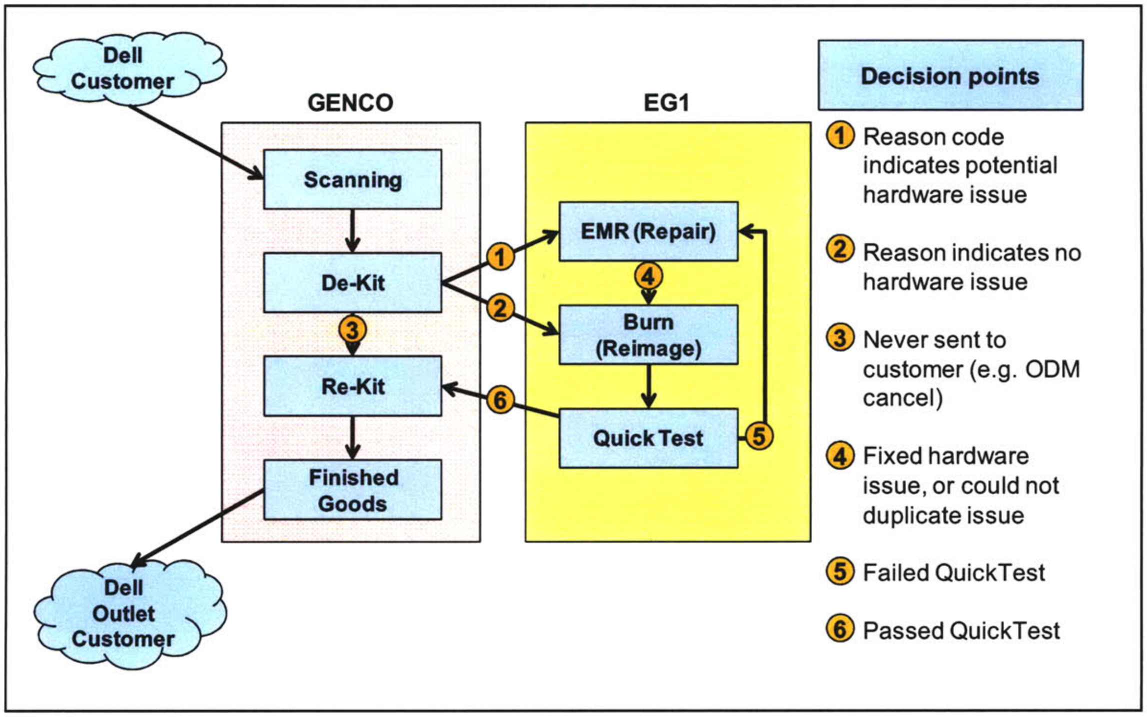

Figure 2: Current refurbish and resale process flow

I. A customer calls Dell, requesting to return a desktop or laptop (or, in some cases, set up an exchange). The Customer Care representative is required to input a "Return Reason Code" for the return. Once the Customer Care representative authorizes the return, the customer ships the system back to Dell.

II. The system is delivered to LaVergne, TN, where a Dell 3rd party logistics partner (GENCO) receives the product from the shipping carrier.

III. A GENCO team member scans the returned product, which triggers a lookup of the product in Dell's IT system. This lookup pulls a variety of information, including numerous system attributes, bill of materials, and return reason code. This information is transferred to GENCO's IT system.

IV. Based on the return reason code, the IT system routes the system to one of 3 stations: Burn, Electromechanical Repair (EMR), or Re-Kit. A product that was "returned" before it was shipped to a customer is immediately sent to Re-Kit since the product should be like new. A product returned with no known hardware problem (based on return reason code) is sent to Burn for a software re-image and system test. A product returned with a stated hardware problem (based on return reason code) is sent to EMR.

V. In EMR, a Dell technician inspects the product and makes any repairs, if necessary. This may involve consuming parts (e.g. replacing a broken CPU with a working CPU). If no problem is found, a "Can Not Duplicate" (CND) is reported. Once EMR fixes any identified problems, it is sent to the Burn station.

VI. In the Burn station, the system is imaged with the appropriate software, and further system testing is performed. If the tests fail, then a technician manually routes the product back to the EMR station. If the tests pass, then the product is routed to Re-Kit.

VII. In Re-Kit, the system is packaged with the appropriate software CDs and cables, and put in boxes. They are then stored in Finished Goods, upon which the system is made available on the Dell Outlet website.

Throughout this process, costs are incurred through both labor and parts consumption. Labor is needed for receiving product, fixing systems, and transporting systems around various stations and work sites. Purchased piece parts are consumed when replacing defective parts in a returned system. For the purposes of this study, fixed costs (e.g. physical work stations, factory space) are treated as sunk costs and are not amortized over the systems. Ignoring sunk fixed costs is acceptable for the purposes of economic decision making, even though it is not accurate for purposes of financial accounting. This is especially true for operational decisions that do not affect large-scale strategic capital decisions.

New channels are developed

ARB strategy: new recovery channels to maximize net recovery at minimal cost.

The process flow described in the previous section describes the process for nearly every returned computer in ARB as of the time of the project. This process has worked well, and gives ARB net recoveries that are believed to be highly competitive with its peers, if not best in class. Net recovery benchmarks are difficult to come by as these are often considered sensitive information.

As described above, ARB has developed a new strategy focused on maximizing net recovery. One method of achieving higher net recovery is through the development of new recovery channels. Recovery channels are the means by which Dell ARB is able to recover value from the returned product. For example, Dell Outlet (also known as direct resale) is Dell's primary recovery channel. The fundamental hypothesis is that ARB is leaving money on the table by effectively forcing every returned product to the direct resale channel, and treating other recovery channels (e.g. sale to a 3rd party recovery partner) as a last resort. Other channels under investigation include teardown, functional bulk sale, and retail sales. The teardown channel is the highest priority for ARB, because it is perceived to have the most value, and is part of a larger "parts strategy" underway at Dell. In the next section, teardown and its rationale will be described in further detail.

General rationale for development of teardown

The "teardown" channel began development in early 2009, and is still under active development as of the publication of this paper. The teardown channel is meant to capture value from a returned system from the individual piece parts, rather than the returned system. Piece parts include computer hardware like CPUs, video cards, and hard drives, but also include non-electronic components like rubber feet and plastics.

These piece parts can be consumed by 3 primary internal Dell "customers." These 3 customers are:

- Dell Service Logistics – Dell must cover warranty for bad parts in systems that customers purchase. Most systems sold by Dell include at least a 1 year warranty; some customers choose to purchase warranties that may run as long as 3, 4, or 5 years. Functional parts from returned computers can be used to fulfill these warranty claims (reducing the need to purchase parts from outside vendors). Warranty fulfillment presents a unique challenge for parts management, since Dell must be able to fulfill warranties on computer that are 3-5 years old. As product lifecycles become shorter and shorter (and the number of products increase), parts management becomes increasingly difficult.
- Dell ARB – Dell consumes parts to fix computers to put on sale in Dell Outlet. This process was described earlier. Essentially, this customer represents cannibalizing some returned systems in order to fix other ones. ARB already does this to a very limited extent for new products where it does not yet have a supply for replacement parts.

- Parts For Your Dell – Dell currently already sells individual piece parts to customers via its website. The website, known as "Parts For Your Dell," allows customers to replace out of warranty parts or to upgrade parts.

Other channels may exist (e.g. sales to outside parts vendors), but Dell believes these are the 3 primary channels it will target first. By establishing the decision capability of properly sorting into 2 distinct recovery channels, Dell can then add additional channels as the operational capabilities become established.

By tearing systems down, there are three advantages that can lead to higher net recovery.

- Reduced parts spend - As highlighted above, the piece parts can have high value through the various parts channels due to the system being out of production. Thus, by reusing the parts, Dell can reduce materials spend (e.g. for part warranty fulfillment)
- Reduced operating expenses - Dell ARB can avoid investing money in fixing a system. For example, instead of investing $300 in parts and labor to fix a $1000 system (resulting in $700 net recovery), it could teardown that same machine (at a cost of $50) to recover $900 in useful parts (resulting in $850 in net recovery).
- Higher sales recovery for Dell Outlet channel – By reducing the number of refurbished systems put for sale on Dell Outlet, Dell should be able to command a higher price point based on supply and demand principles. Dell frequently runs promotions on Dell Outlet based on high inventory levels. With lower inventory levels, there should be fewer promotions needed.

Importance of routing

The key question at hand, and the focus of this project, is how to determine which systems should be torn down, and which systems should be remanufactured and resold on the outlet website. The goal is to maximize net recovery. However, as this is not simply a theoretical project, outside constraints such as complexity and IT implementation must be considered (and minimized) as well. A primary driver of success is the ability for the proposed system to be realistically implemented into the ARB process flow.

1.3. Hypothesis and methodology

The hypothesis is that the intelligent disposition of systems to teardown will generate higher overall net recoveries. This paper proposes a mental model, framework and corresponding decision system that can be easily incorporated into Dell's (or a similar company's) disposition system. This decision system is referred to as SORT (Systems Optimization Routing Tool) and is implemented into the production control workflow at Dell. Although it is not yet running at Dell, the usage of SORT is simulated to compare it against a baseline without the decision system (namely, human intuition).

1.4. Thesis structure

This paper is organized into six chapters:

- Chapter 1 provides an overview of the problem definition, and provides background on reverse logistics at Dell

- Chapter 2 contains a review of existing literature covering Dell's overall supply chain, general reverse supply chain, and decision systems in reverse supply chains. This literature review demonstrates the lack of prior work in addressing the Dell's specific problem of system-by-system decision methodology in the reverse supply chain.
- Chapter 3 describes the methods. Specifically, it describes the proposed decision system (SORT), including rationale and implementation. The decision support system, requiring no additional IT work, is implemented at Dell.
- Chapter 5 contains the findings. Specifically, the usage of SORT is demonstrated, including simulated results and estimation of savings.
- Chapter 6 contains conclusions, proposed additional work and remaining questions.

2. Literature review

2.1. Introduction

There is a significant amount of literature in the general areas of Dell's supply chain, reverse logistics, and quantitative models in reverse logistics. This section provides a summary of important literature in these 3 areas. A review of the literature indicates that Dell's specific need of system-by-system decision system has not been previously documented.

2.2. Review of discovered literature

Previous external research provides an excellent overview of Dell's supply chain, focusing on its closed loop nature (Sameer Kumar and Craig 2007). Some minor inaccuracies exist, but the findings are largely correct. They base their analysis on public documents and had no internal Dell information.

External benchmarking surveys of over 250 companies have identified best practices and best-in-class performance. They observed that across all industries, the top quintile of companies averaged 64% net recovery. Within high-tech, the average net recovery was 28% (Aberdeen Group 2007). This would put Dell in the top 5-10% of all companies, and likely the best in class within the industry.

HP's reverse supply chain for its printers has been written as a case study (Neeraj Kumar, Van Wassenhove, and Guide Jr. 2002). The case study references a decision model that incorporates product life cycle, product value and condition, and economic "best use," as disposition criteria. It is perhaps the literature that references a tool most similar to one that Dell is seeking to create. Unfortunately, it is not the focus of the case study.

Blackburn provides a good overview of key issues in reverse supply chains. Specifically, the paper summarizes the idea and value of "preponement" in reverse supply chains, as well as the marginal value of time (Blackburn et al. 2004). Preponement is the principle of making product disposition decisions as early as possible in order to avoid processing returned products with little to no remaining value. This parallels the principle of postponement in the forward supply chain, where product differentiation decisions are made as late as possible.

System dynamics has been used to create a virtual "flight simulator" for management to understand reverse logistics in different operating environments (Tan and Arun Kumar 2006). However, it does not contain a logic to "sort" products into various recovery channels.

Wadwah et al propose a fuzz-set theory based multiple criteria decision-making model to help a company decide on which remanufacturing channel to pursue (Wadhwa, Madaan, and Chan 2009). This model takes inputs from management, asking them to assess the priority of different strategic issues and the favorability of those issues. This provides a numerical output to rank the favorability of various strategic disposition options. However, it does not provide unit-based decision logic.

Zikopoulos and Tagaras examine the value of sorting prior to disassembly (Zikopoulos and Tagaras 2008). Their analysis assumes some sorting capability is possible, and identifies a formula to determine the economic utility of using the sorting capability, based on varying levels of Type I and Type II errors as well as the costs. Their research is useful in understanding the value, but does not provide the actual decision logic in sorting.

Wu proposes that Infocus, a projector manufacturer, teardown returned product for the service parts, in order to improve overall profitability (Wu 2006). Wu creates both a complicated stochastic model and a simpler heuristic model to determine "fill-up-to" inventory levels. This paper shows the profitability of teardown, but does not provide a system-by-system disposition logic.

Guide demonstrates that a quick sorting logic helped HP reduce costs and lead-times (Guide Jr., Van Wassenhove, and Muyldermans 2005). HP's repair work was outsourced to an ODM in Asia, resulting in significantly longer lead times than Dell's current state due to the shipping time. Like Wu, it does not propose the actual sorting logic.

Kleber proposes an inventory model for a multiple choice disposition logic with constraints such no stockouts (Kleber, Minner, and Kiesmüller 2002). Interestingly, it proposes postponement of decision making, conflicting with the preponement model of Blackburn.

Kaga presents an application of real options to reverse logistics, discovering the option value of keeping in-house repair as an option for backup to the standard swap process (Kaga).

Fleischmann et al (1997) provides a dated, but good summary of available literature on quantitative models in reverse logistics around 3 categories: distribution planning, inventory control, and production planning. The summary of literature on selection of recovery options was particularly helpful (Fleischmann et al. 1997).

Galbreth and Blackburn provide a proposed sorting policy using a variant of the newsvendor model. In this model, the decision variable is the amount of returned product to acquire (not a realistic assumption in Dell's case). They optimize for minimal cost while satisfying a stochastic demand function. Their primary insight is the development of an optimal portion of goods to send to remanufacture (Galbreth and Blackburn 2006).

Fleischmann provides a case example at IBM of using decision modeling in a teardown process (Fleischmann et al. 2004). Specifically, it identifies an optimal inventory management policy to minimize costs in the development of a new disassembly process. The decision here is to either recycle or teardown.

Mitra presents a formulation for maximizing revenues when deciding between multiple recovery channels, based on various demand curves (Mitra 2007).

2.3. Summary of literature review

There is a significant amount of literature around reverse supply chains and reverse logistics, but the literature focuses primarily around inventory management in reverse logistics and not operational decision models. The work in presented in this paper should bring new insight into the operations management in a reverse logistics environment.

3. Methodology

3.1. Introduction

The Methodology section contains a discussion on how and why the decision model will incorporate a feature currently existing in Dell's IT system. This feature is CAPTURE, which allows the IT system to route a preset number of systems to a user-defined recovery channel. Next, details of the model, and what metrics were used to judge the model are provided.

3.2. Decision system framework based on existing IT feature

As a large, global organization, Dell has complex IT systems, where proposed changes must go through a rigorous approval process. Thus, the implementation of SORT attempted to minimize any required IT changes and approval. In devising an implementable decision system, the author investigated Dell's existing IT system for features that could be used to route computers to the optimal recovery channels.

The existing IT system is a Dell-homegrown solution named MSS2. It has numerous features and capabilities. The CAPTURE feature in the IT system was found to be a suitable method for routing systems. CAPTURE is a feature that allows a supply chain planner to configure a certain number of systems fitting a user-defined profile to be routed to a user-defined routing position. Consequently, the author decided that SORT would provide inputs into CAPTURE. This would avoid the costly expense and complexity of developing a new routing system outside of MSS2, or require significant IT investment to modify MSS2.

3.3. Detailed model description

This section describes the model in detail. The model's general approach, assumptions, and implementation are discussed. Fundamentally, the model is data-driven based on estimates of net recovery through direct sale and teardown. An optimal number of systems to send to teardown will be found, in order to maximize overall net recovery. Figure 3 provides a high level framework of this methodology.

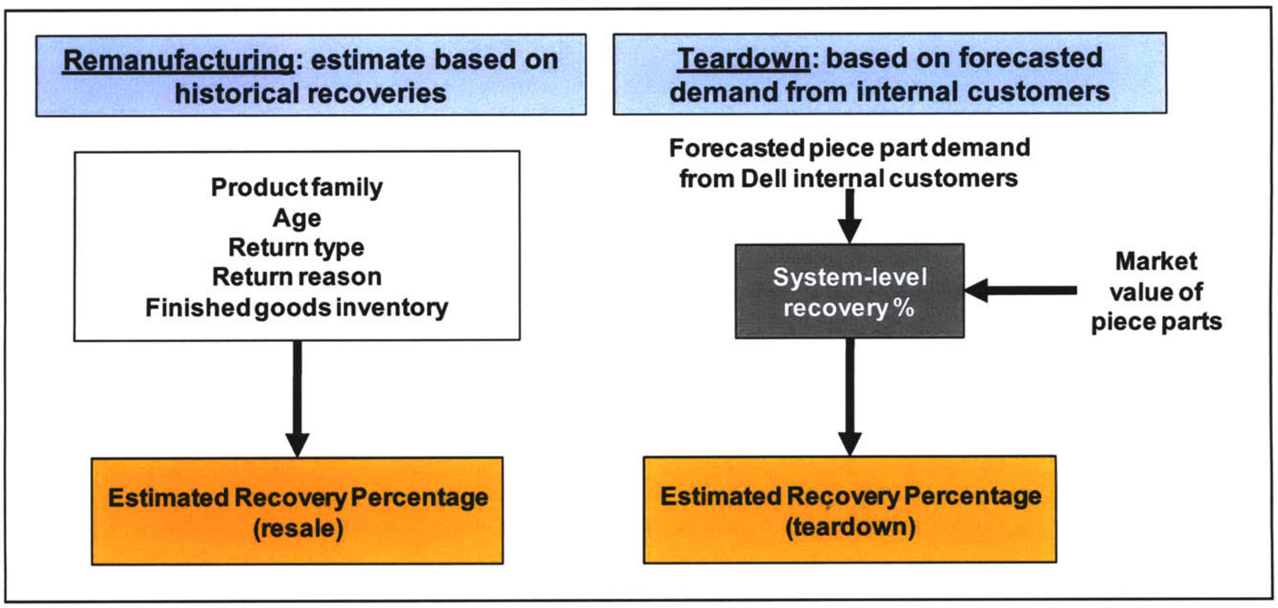

Figure 3: Framework of net recovery estimation method

Estimating net recovery through direct sale

The first step toward is to estimate net recoveries through direct sale. The significant amount of historical data can be used to estimate future net recoveries. There are numerous known characteristics known at the time of the receipt of product, including:

- Product family – the specific product line describing the internal system hardware and configuration. Families are given internal code names at Dell. Generally, each family aligns with one public commercial product name (e.g. Inspiron 1420).
- Age – the time between the original order date and the receipt of the returned product
- DPS Type – the type of return. Returned products can be due to end of lease, a customer return, or a customer exchange.
- DPS Reason Code – the specific coded reason describing the reason for return. These product reason codes are inputted by a Dell employee (e.g. a customer service representative processing the return request). The reason code is meant to convey information on the reason for the return (e.g. broken LCD).

However, despite knowing this information, one of the biggest complicating factors is the high variability of net recovery, even when comparing systems with similar characteristics. Regression analysis, along with simpler heuristics, is used to estimate net recoveries. Results of this analysis, and their use into the overall SORT model, is discussed in Findings.

Estimating net recovery through teardown

As the teardown channel does not exist, there is no historical data for the channel. Thus, the author devised a mental model for understanding and predicting recovery from teardown. Teardown recovery decreases with each successive machine sent to teardown, because different piece parts have different demands. A curve can be built representing the marginal recovery of each successive machine torn down. To demonstrate the mental model underlying this teardown marginal recovery curve, a simple example is introduced. Imagine the following scenario:

- Simple computer: a Dell computer system composed of only two piece parts (a hard drive and a CPU)
- Part valuation: The hard drive is valued at $50, and the CPU is valued at $100.
- System valuation: The system is valued as the sum of the parts ($150).
- Attach rate: There is one CPU and one hard drive per computer
- Defect rate: There are no defects in the CPU and hard drive.
- Part demand: There is a different demand for the CPU and hard drive. The monthly demand for CPUs is 200, and the monthly demand for hard drives is 60.
- Piece part recycle: If Dell tears down a computer and has no use for one or more of the piece parts, it is worth $0 to Dell.
- Teardown costs: It costs $0 to teardown this computer.

Clearly these assumptions are false, but they are presented here for illustrative purposes. Based on these simplifying assumptions, a "teardown recovery curve" can be built. This curve calculates the expected net recovery of each successive system torn down. Figure 4 represents the teardown recovery curve of the simplified product described above.

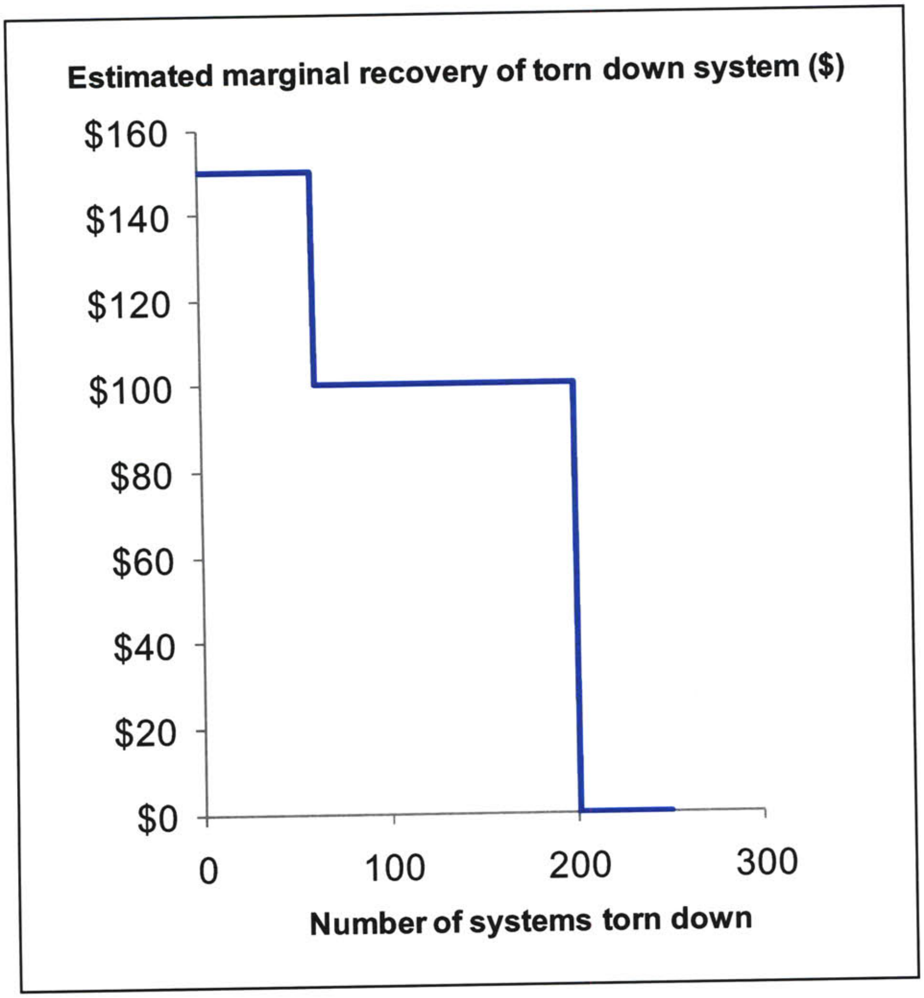

Figure 4: Conceptual model of estimating recovery through teardown

As seen above, the first 60 systems have a full recovery of $150 (the full value of the system), since there is a demand for at least 60 hard drives and 60 CPUs. However, once the 61st system is torn down, the value of the hard disk is lost. The recovery drops to $100 (the value of the CPU). This holds true until the 201st system is torn down. At that point, Dell has no need for any of the parts, and thus recovery drops to $0.

The above example is clearly extremely simplified and unrealistic. However, it conveys a mental model useful for thinking about expected recovery from teardown. The key insight is teardown recovery decreases as more systems are torn down.

Theoretically, Dell should teardown until the estimated marginal net recovery is below the estimated direct sale net recovery for a particular group of systems. The graph below demonstrates this concept in graphical form.

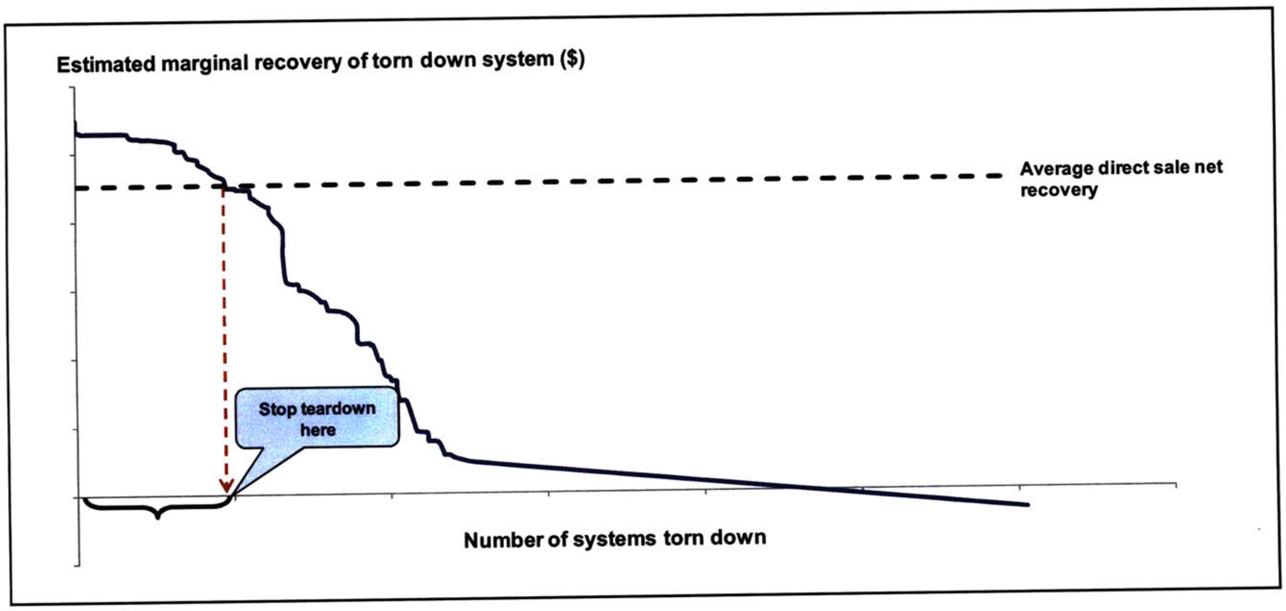

Figure 5: Model for finding optimal teardown target

Here, the solid line represents the estimated marginal recovery of a torn down system. The dashed horizontal line represents the average net recovery through direct sale. As the chart indicates, the visual representation of the mental model is to teardown systems until the solid teardown line crosses the dashed direct sale line.

A question yet unaddressed is which systems should be torn down. Some groups of returned computers, such as those never opened by a customer, are easy to dismiss as candidates for teardown since they are known to have very high direct sale net recoveries. In the results section, insights from analysis of historical net recoveries will allow for identification of a subgroup of systems that have historically lower net recoveries.

Assumptions

A core assumption is that teardown net recovery is a function of the number of machines torn down and the demand for parts. The quality of the machines is not factored in to net recovery estimations. This simplifying assumption is driven by two reasons

- Intuition that tearing down too many machines results in low net recovery, due to oversupply of parts that have no demand.
- No data exists that matches quality codes (i.e. DPS reason codes) with teardown net recovery.

Another important assumption is that product families are relatively homogenous in composition and net recovery averages. This is a simplifying assumption that does not accurately reflect reality, as will be shown in the Findings section. However, Dell's goal is to make the right decision within a product group on average.

Implementation

To implement this model for optimal teardown recovery calculation, the author created a Microsoft Excel workbook to be used by Dell's materials planners. The spreadsheet outputs a specific number of machines to teardown for each family within a given time period. For example, the SORT workbook would tell suggest routing 60 returned computers of product family A to teardown in the next 30 days. This number can be inputted into the MSS2 CAPTURE configuration, resulting in MSS2 routing systems to teardown until the optimal number has been reached.

3.4. Resolution of implementation complications

During the process of implementing the SORT model, many complications were discovered. In this section, two important complications and their corresponding solutions are discussed.

Part substitutions

Problem

The most significant complication encountered is that of part substitutions. Many parts are substitutable for one another. This is especially true for commodity piece parts (e.g. a Toshiba 40GB 2.5" hard drive can be swapped out for a Samsung 40GB 2.5" hard drive). These substitutions must be incorporated into SORT's understanding of piece part demand.

Without incorporating substitutions, Dell could easily miss opportunities for recovering values from piece parts. For example, imagine a scenario where there is demand for a Western Digital hard drives. However, a family of systems being returned contains Seagate hard drives. The Seagate and Western Digital hard drives are substitutable, and thus, there is value in recovering the hard drive from those machines. However, if SORT does not realize the substitution, then it will incorrectly assume there is no value in those hard drives. This will result in understating the number of machines Dell should tear down.

Resolution

To address this problem, the author developed a SQL query to build "part groups." Every part was assigned to a "part group", and these groups became the new "parts" in a machine. There was already an official substitution list that specified A to B relationships (e.g. Sound Card A can be switched out for Sound Card B). However, no comprehensive grouping lists existed.

Inconsistent bill of material information tracking

Problem

A similar problem was one of bill of material information. In the methodology for pulling the bill of materials, SORT relies on the information contained in MSS2. MSS2 pulls the information from a variety of Dell sources when the returned system is scanned in. Computer systems, like most assembled products, have multiple levels of bill of materials. For example, in a desktop, a chassis "part" may contain a motherboard as a sub-part. Similarly, for a laptop, a laptop "base" may contain the motherboard as a sub-part. MSS2 pulls bill of material information as needed, on a system by system basis. Thus, two physically identical systems may appear differently in MSS2. A further challenge is that Dell may order parts at any of these levels, and the parts forecasts may not align with the part information in MSS2.

Resolution

The bill of material information problem was resolved in a manner similar to the resolution of the part substitution issue. However, there was no easily retrievable bill of materials data source. Consequently, the work instructions for SORT require some manual addition of information such that chassis and laptop bases are made to appear as equivalent parts with their motherboard sub-parts. In the future, MSS2 may automatically retrieve all levels of BOM information for all systems.

3.5. Metrics/hypothesis

To evaluate SORT, important metrics should improve based on a more optimal disposition. As there are no existing baseline processes for determining teardown versus resale, a baseline must be created. For baseline comparisons, an assumption is made that a materials planner is making a "best guess" as to the number of systems to send to teardown.

Higher direct sale sales recovery

Fewer systems being resold should mean higher sales prices. Dell Outlet frequently runs discounts. These discounts are often targeted at systems that have high inventories. By reducing the flow of volume into finished goods, Dell should be able to reduce the frequency and amount of promotions offered.

Lower spend in refurbishment

If Dell is able to route the worst systems away from the high touch processes (specifically EMR), Dell will spend less refurbishing. This will result in a lower spend per system in refurbishment. As shown in Figure 6, the worst systems (by net recovery), account for a very disproportionate spend of both labor and parts consumption. As these systems are routed to teardown, total refurbishment spend should decrease.

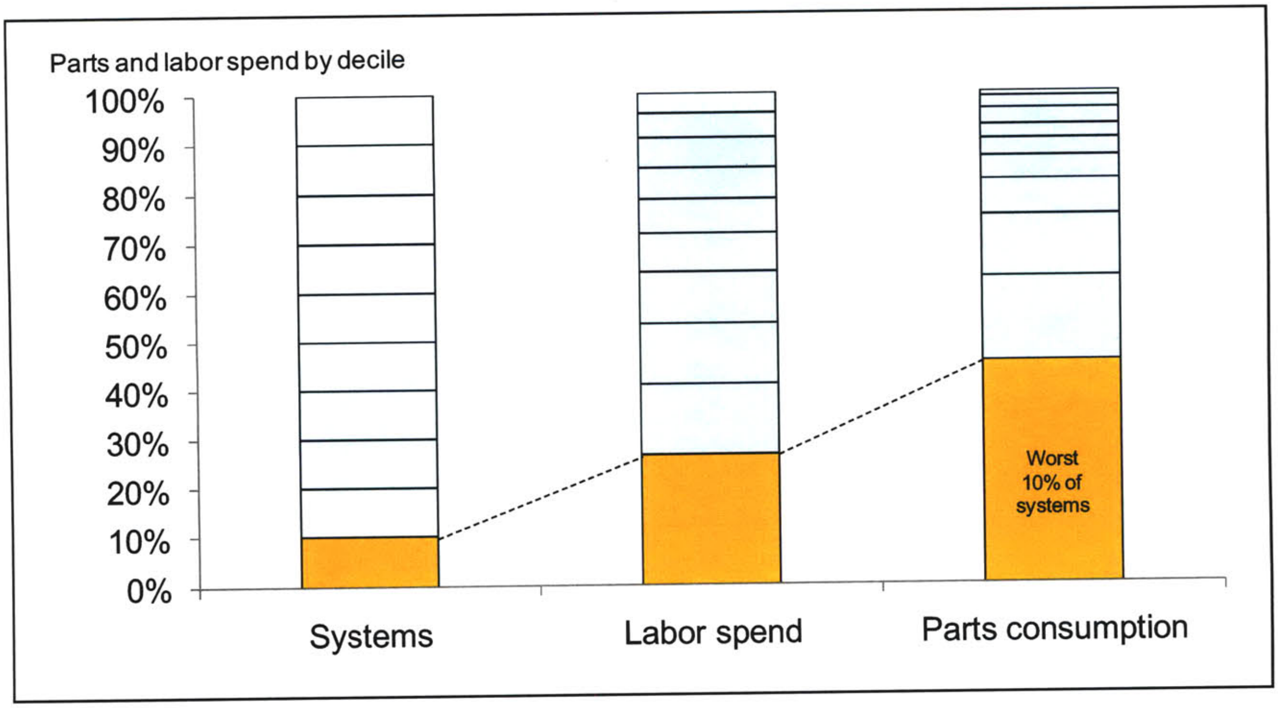

Figure 6: Parts consumption and labor spend by net recovery decile

Higher direct sale net recovery

Higher sales recovery and lower spend per system should result in higher direct sale net recovery.

Reduced consumables spend

ARC and Dell Service Logistics should both have lower consumables spend. By transferring parts from torn down machines, they can avoid purchasing parts from traditional parts suppliers. These parts suppliers include part vendors, ODMs, and gray market vendors. Occasionally, Dell pays above the original cost, especially for older parts. This is particularly true when purchasing from gray market vendors.

Higher overall net recovery

All factors above should lead to higher overall net recovery for Dell ARB. As net recovery is the most important metric for Dell ARB, the findings will focus on improved overall net recovery.

4. Findings

This section reviews the findings from the model and the data collected. Specifically, the attempts at identifying drivers of direct sale recovery through regression analysis will be discussed. Historical data is found to have low predictive power in direct sale recovery, but some simple heuristics are found for identifying groups of systems that have lower direct sale net recoveries. Next, example inputs and outputs for the implementation of SORT (the teardown target model) will be shown, demonstrating the actual use scenario of the model.

4.1. Poor predictive power for direct sale recovery

A first step in building the model is to understand whether net recoveries of systems in direct resale can be predicted. As described above, Dell has a significant amount of historical data regarding returned systems that are refurbished and resold. The most important factor driving net recovery is the product family.

Weak R^2 across all systems

The initial regression attempts to find factors driving net recovery. Factors considered are: age, product family, return type, return code, and original sales channel. Multiple regressions are performed, including both linear and logistic regressions. The age variable is also manipulated in various ways, including log transformation and binning based on time buckets (e.g. 3-6 months, 6-12 months).

Based on multiple analysis, two important discoveries are made. First, the most significant driver of net recovery is the product family. Secondly, the other factors do not seem to have much significance in affecting net recovery.

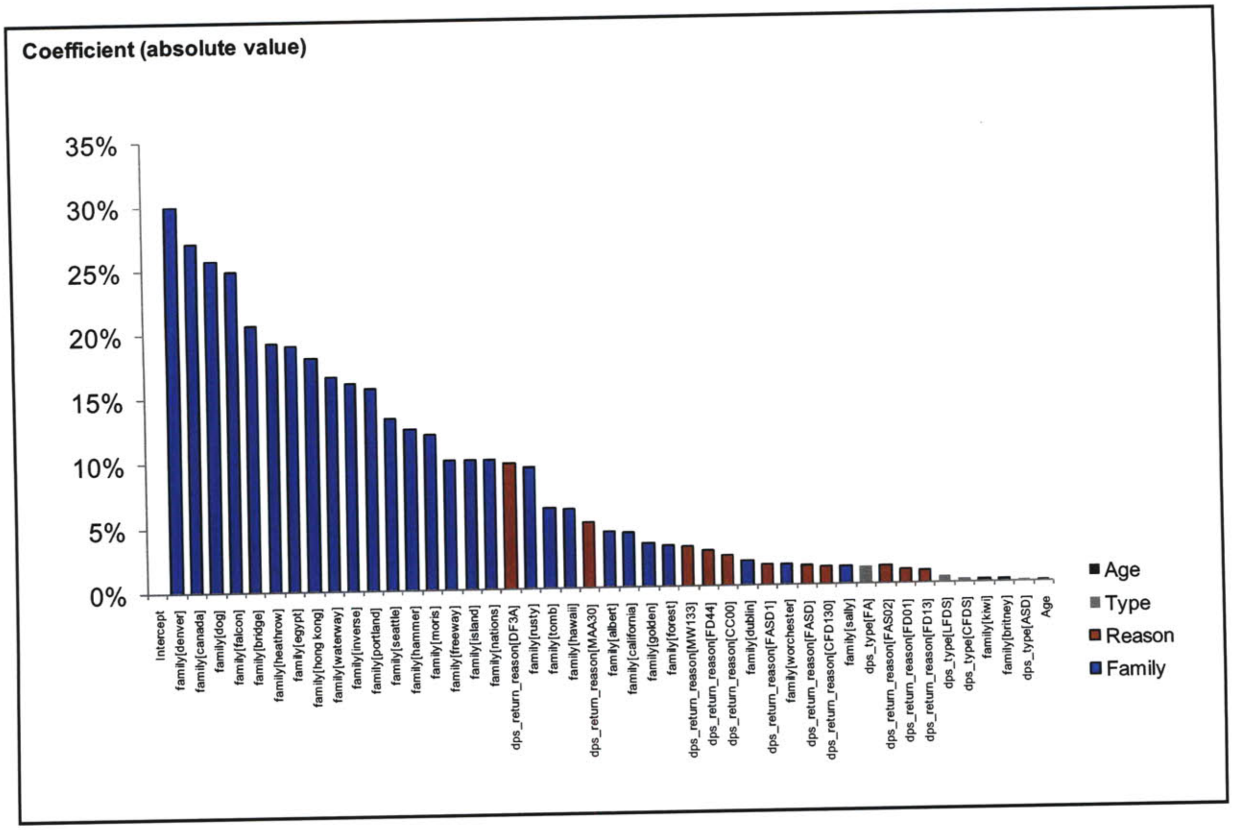

Figure 7: Coefficient of various factors

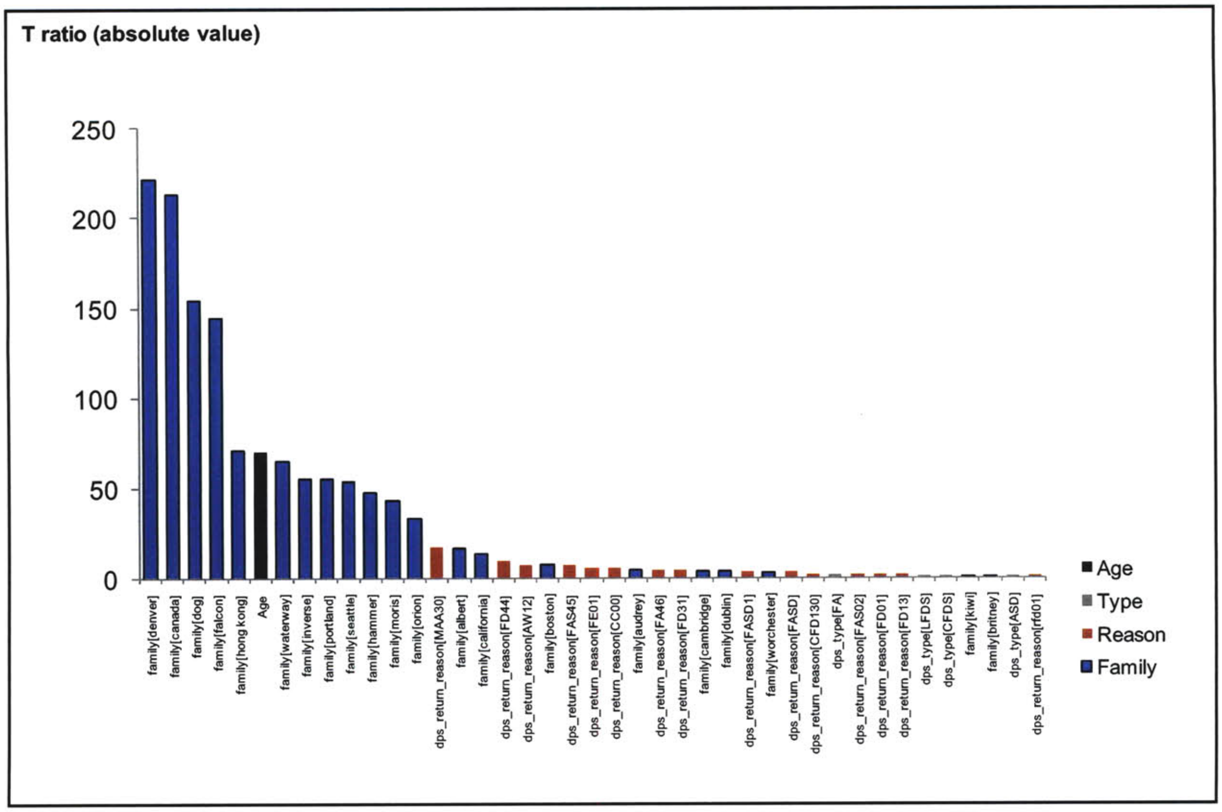

Figure 8: T-ratio of various factors

In Figure 7, it is shown that the most influential factors are the product families (shown here as blue bars). Figure 8 shows product family is also the factor with the highest confidence (along with age).

R^2 for various families

Consequently, the next step involved identifying potential cross-factors to understand if there were any family-specific factors driving net recovery. This meant running individual regressions by product family. There were no obvious factors driving net recovery in any families. Regressions were run on product families A, B, C, D. The sample data is from August

2008 through December 2008. The results comparing predicted net recovery percentages and actual net recovery percentages are shown below.

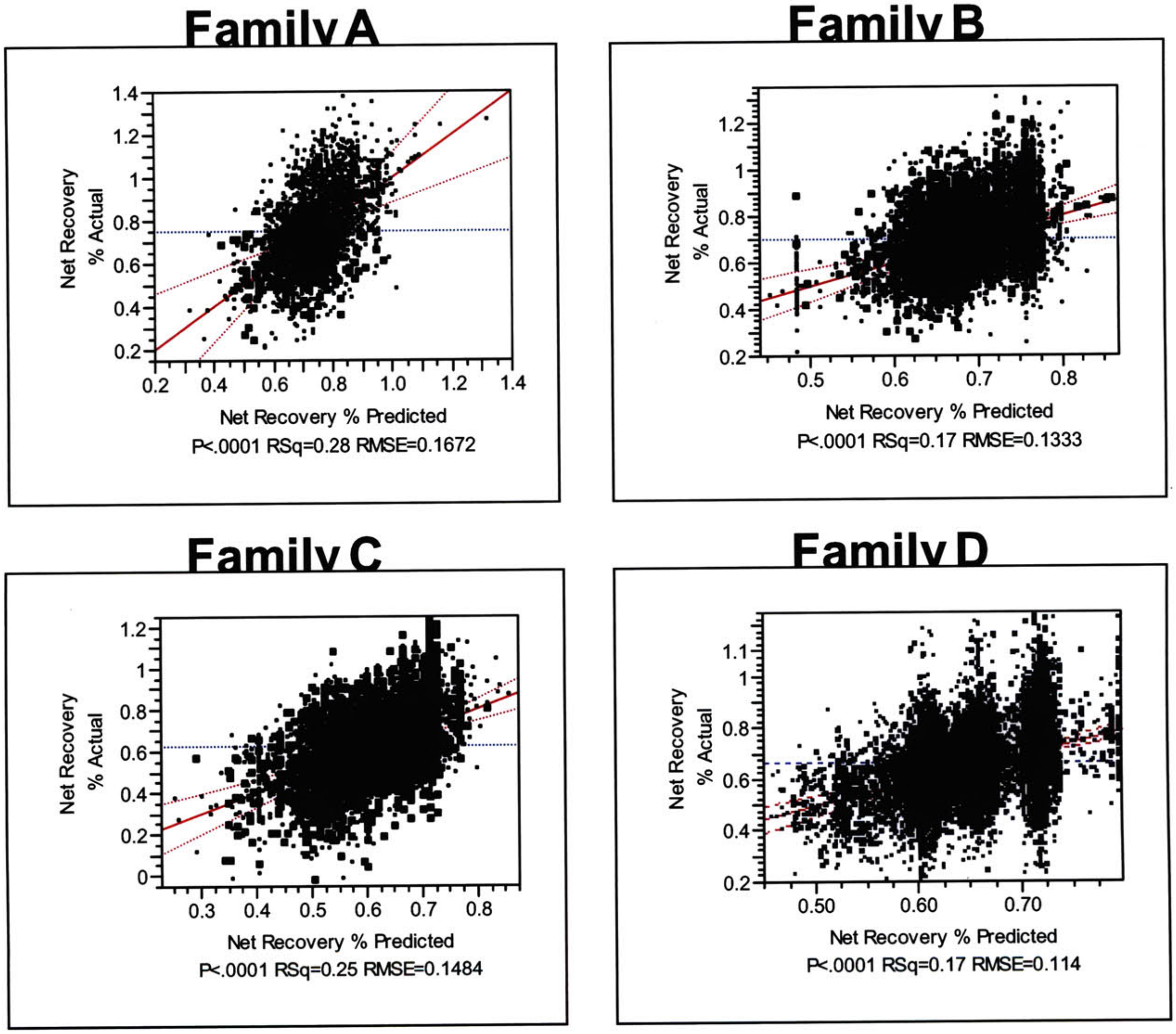

Figure 9: Predicted vs. actual net recovery, by family

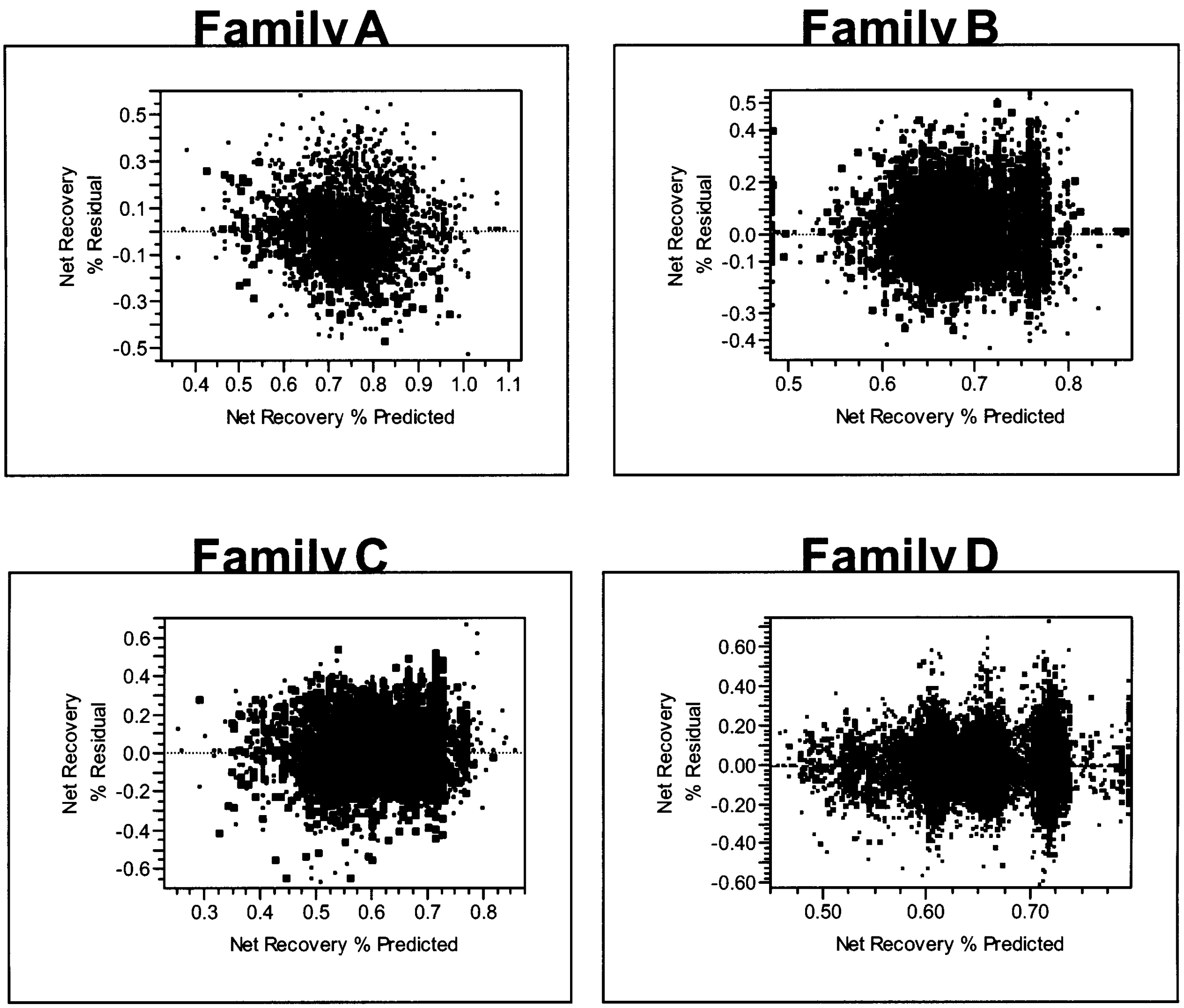

Figure 10: Residual vs predicted net recovery, by family

As seen in Figure 9, the linear regressions do not provide an accurate predictor of net recovery. The four families have R^2 of 0.28, 0.17, 0.25, and 0.17. Accurately predicting direct sale net recovery based on historical sales did not appear to be a viable undertaking. An examination of the residuals in Figure 10 also shows limited evidence of any systemic error.

Other influential factors in net recovery

The regressions point to very limited predictive power in estimating net recoveries through direct resale. Thus, there will be limited confidence in pre-determining systems with low net recoveries that could be candidates for teardown. However, there is still an important need in identifying groups of systems that have lower net recoveries on average. It must simply be recognized that the accuracy of such predictions will be low.

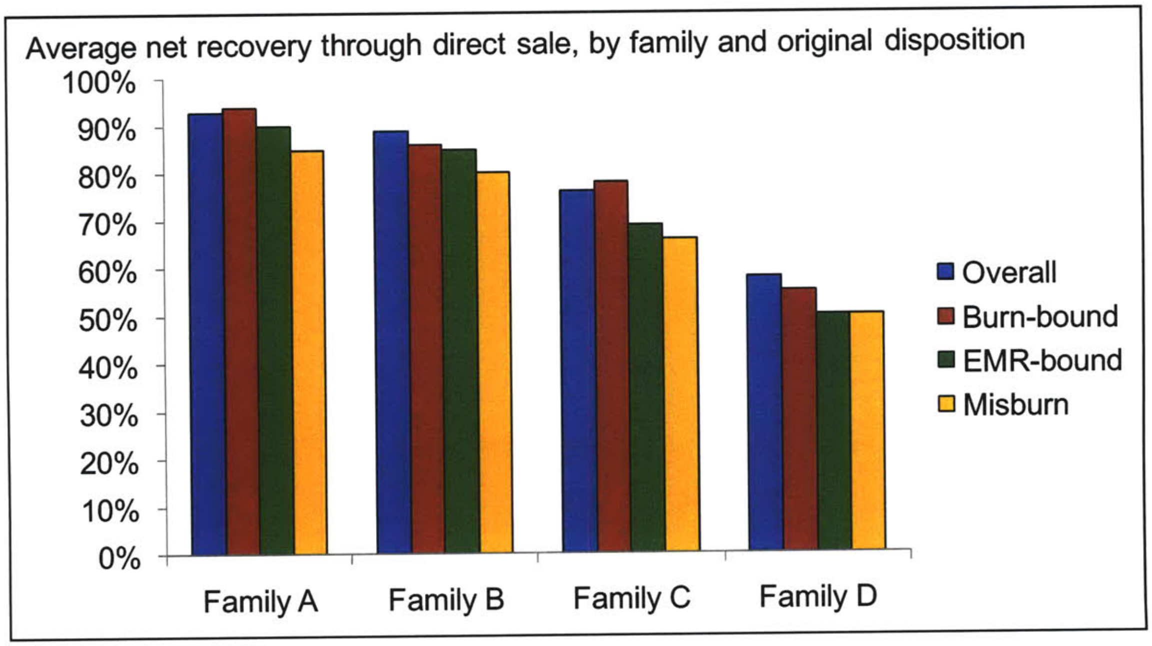

Figure 11: Average recovery through direct sale, by family and disposition

Figure 11 shows average direct sale net recovery across 4 product families, segregated by 4 different categories of systems. The 4 categories of systems are:

- Overall: All systems within a product family. This is a superset of all below categories.

- Burn-bound: Systems that were originally routed to burn, based on the DPS Reason Code. The reason for return was thought to be hardware related, and only a hard drive wipe and re-imaging would be necessary.
- EMR-bound: Systems that were originally routed to EMR, based on the DPS Reason Code. The reason for return was thought to be hardware-related, and a Dell technician would inspect the machine and make repairs if necessary.
- "Misburn": Systems originally routed to the Burn station, but then were thereafter sent to EMR because it failed a system test. The author deemed these systems "Misburns" because they were misdiagnosed systems that should have been sent to EMR, but were sent to Burn. This is a subset of the "Burn" group described above.

From the chart, it is observed that Misburns have, on average, lower direct sale net recoveries. Specifically, it is worth noting that Misburns have lower net recoveries than even EMR-bound systems. This can be explained by the high error rate in the original routing. This is in line with the regression analysis which demonstrated low predictive power for DPS reason codes. Mis-burns are more likely to require investment in labor and replacement parts than EMR-bound machines. Misburns have gone through a software diagnostic test indicating a hardware failure, while EMRs only have a unreliable reason code indicating potential hardware failure.

A high percentage of original dispositions are incorrect. Figure 12 contains approximations of the percentage of original dispositions that were incorrect.

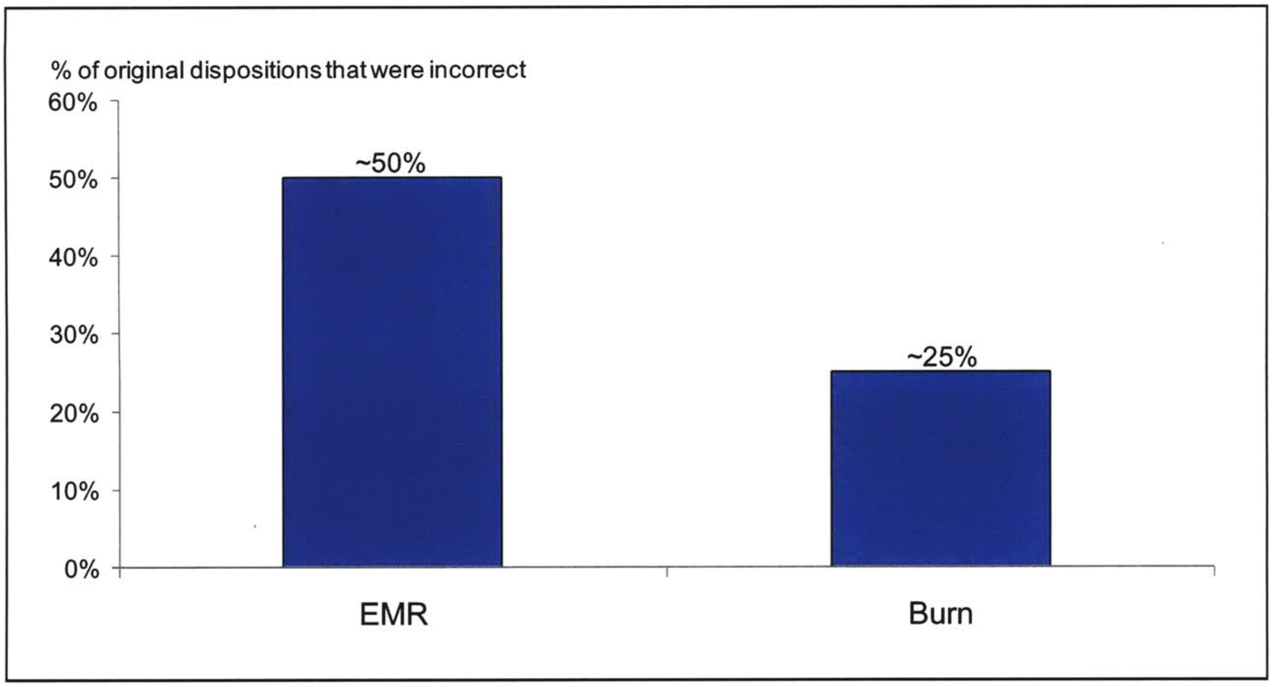

Figure 12: Percentage of original dispositions that were incorrect

Approximately half of systems originally routed to the EMR station resulted in a "CND" (Can Not Duplicate). A quarter of systems originally routed to the Burn station failed the diagnostic test, resulting the system being routed to EMR. As the original disposition (routing) is based on DPS reason codes, this is not surprising.

Based on this analysis, SORT is designed to use Misburn systems as the group of systems that will be sent to teardown. Operationally speaking, this means systems that fail out of diagnostic test would be potential teardown candidates.

4.2. Description of implementation

This section contains a more concrete description of the Excel workbook used to identify the optimal number of systems to send to teardown. Workflow descriptions are presented to describe the process for using the Excel workbook. Additionally, an example case study with inputs and outputs is provided.

Workflow

In the family-grouping of teardown capture setting, the Dell Global Ops Command Center planner will aggregate data together to input into SORT (implemented as an Excel model), which returns a number to teardown for that month. Each product's teardown target will be inputted into MSS2 in the CAPTURE feature.

The high level steps are as follows:

a. Input historical direct sale net recoveries by product family
b. Translate forecasted piece part demand to estimated system net recoveries through teardown
c. Synthesize and calculate optimal teardown target

In implementing the SORT tool, the author decided to have all decisions made at the product family level. This was decided upon for two reasons. First, decisions are often already made at a product family level. In particular, a decision to initiate a teardown program would be made on a family by family basis. This is because each product family would likely require unique teardown work instructions and training program. Secondly, deciding teardown targets at a product family granularity is also more optimal. The analysis around the drivers of net recovery showed that product family was the most significant driver of direct sale net recovery. For these two reasons, deciding teardown targets by family made more sense than other alternatives (e.g. setting a teardown target relevant for all incoming systems, regardless of family).

While each product family receives its own teardown target calculation, SORT can calculate multiple families at once. This reduces the data collection and procsesing burden on the Dell Planner.

Inputs, calculations, and outputs

Numerous inputs are required for SORT. Each input type is contained within a single Excel worksheet. The following lists the various inputs required, as well as a sample screenshot of the input in the SORT workbook.

Inputs

Step 1: Input historical direct sale net recoveries by product family

Rank ($)	Rank (%)	Family	Net recovery % (EMR)	Net recovery $ (EMR)	Net recovery % (Misburn)	Net recovery $ (Misburn)	Net recovery $ (all)	Ranked family ($)	Ranked family (%)
1001	1002	Dragon	30%	$ 392	25%	$ 10	$ 432	1001Dragon	1002Dragon
1002	1003	Lion	80%	$ 246	70%	$ 230	$ 274	1002Lion	1003Lion
1004	1001	Wolf	44%	$ 499	20%	$ 900	$ 539	1004Wolf	1001Wolf
1003	1004	Dog	90%	$ 623	85%	$ 573	$ 644	1003Dog	1004Dog

Figure 13: Net recovery input worksheet in SORT

As the first step, the Planner must calculate the net recoveries in both dollar and percentage figures for the product families in question. The method for retrieving and calculating is Dell-specific, and is not included as part of this thesis. Both EMR and Misburn net recoveries are calculated and inputted, as seen in Figure 13. The timeframe for this information is set by the planner to 30 days for high-volume product families, and 90 days for low-volume product families.

Step 2: Translate forecasted piece part demand to estimated system net recoveries through teardown

Multiple detailed sub-steps are required here. Included only are the significant ones involving analysis. Methods of pulling data specific to Dell are not included.

Part groupings

	A	B	C
1	part_number	part_group	
2	YY993	YY993	
3	YY969	YY969	
4	YY922	YY922	
5	YY881	9F029	
6	YY875	JY411	
7	YY859	YY859	
8	YY838	YY838	
9	YY823	UT225	
10	YY821	YY821	
11	YY809	YY809	
12	YY808	DD034	
13	YY807	YY807	
14	YY806	YY806	
15	YY805	YY805	
16	YY782	YY782	
17	YY778	G493H	
18	YY776	YY776	
19	YY770	G493H	

Figure 14: Part groupings worksheet in SORT

Each part number is associated with a single part group. Parts groups are calculated based on a part substitution list contained within Dell. Because the part substitution list changes over time, and it's easily retrievable, the Planner pulls the data and calculates the new part groups. For nomenclature purposes, the name of each part group is simply the name of one of the part numbers.

Piece part demand

	A	B	C	D
1	Demand source	Part_number	Demand qty	part_group
2	ARC	HY385	1463	HY385
3	ARC	Y9530	847	Y9535
4	ARC	PN424	701	C6844
5	ARC	T7570	570	T7570
6	ARC	Y9540	562	YK119
7	ARC	F491C	551	D7377
8	ARC	YK196	468	YK196
9	ARC	NK750	453	NK750
10	ARC	GT027	443	GT027
11	ARC	DR160	402	UC172
12	ARC	D803C	389	D7377
13	ARC	M353G	312	M353G
14	ARC	NC929	281	NC929
15	ARC	WK007	281	C6844
16	ARC	H022C	248	D7377
17	ARC	JP208	211	CR329
18	ARC	RY007	208	RY007
19	ARC	PR296	200	PR296
20	ARC	GX166	192	GX166
21	ARC	F6761	184	C6842
22	ARC	NR694	175	CR329
23	ARC	FU289	163	FU289
24	ARC	JR356	159	JR356

Figure 15: Piece part demand worksheet in SORT

The Dell planner will next need to collect forecasted demand from each of the potential customers (Service Logistics, Returns Refurbishment, and Parts For Your Dell). As seen in Figure 15, the part group is incorporated into the dataset based on the part number.

Received part count, by family

	A	B	C	D	E	F	G	H	I	J	K
1	part_number	part_id	description	total_qty	issue_code	box_code	commodity_code	standard_cost	family	familiy-o	part_group
2	0P030	55793	Description A	2	6	D5	NBM	5.48	Dragon	1002Drag	0P030
3	0R115	55420	Description B	1	6	F0	NBD	36.48	Lion	1003Lion	PY392
4	35FNF	230474	Description C	28	6	A0	MCH	1.25	Wolf	1001Wolf	35FNF

Figure 16: Received part count worksheet in SORT

To understand the quantity of each parts being received by the returns center, the planner next pulls in information about part count. For each part number and product family combination, the quantity received in returned systems is pulled. Description, commodity types, standard costs are also included. A screenshot of a sample worksheet is shown in Figure 16.

Received system count, by family

C	D	E	F
Family	system_count	emr_system_count	misburn_system_count
Dragon	2,363	914	376
Lion	5,991	1,649	1,031
Wolf	7,154	1,976	832
Dog	13,108	3,109	1,561

Figure 17: Received system count worksheet in SORT

System counts are also inputted, as seen in Figure 17. System counts may differ from part count due to differences in attach rates for each part and configurations for each system. For example, various system configurations mean some systems have 1GB of RAM, while others have 2GB of RAM. In some systems with 2GB of RAM, there are 2 sticks of 1GB memory, while in other systems there is 1 stick of 2GB of memory.

Other inputs

Various other inputs are also required. These include:

- Default recycle recovery – This is the percentage recovery that can be achieved through a parts-as-is channel, which includes recycling. This is used as the recovery for parts that have no demand through Dell's internal parts customers.
- Teardown cost per unit – This is the cost to tear down one system.
- Part failure rate – This is the percentage of parts that are expected to be faulty. This can be specified at a part or commodity level.

Calculations

Once the inputs are provided, numerous calculations are performed within the SORT worksheet. A brief outline of the significant calculations follows. Parts are referred to as *x*, and product families are referred to as *y*.

- For each family, the list of parts associated with the family is collected onto one sheet
- The "good" attach rate of each part is calculated.

$$GoodAttachRate_{x,y} = \frac{QuantityReceived_{x,y} \times (1 - Failure_{rate_x})}{QuantityReceived_y}$$

- The full value of a torn down system is calculated, assuming infinite demand for parts.

$$FullValueTeardown_y = (\sum_x (GoodAttachRate_{x,y} \times PartCost_x)) - PerUnitTeardownCost$$

- The average recovery value of each part from each system in that product family is calculated.

$$AveragePartRecoveryValue_{x,y} = PartValue_x \times GoodAttachRate_{x,y}$$

- For each part, calculate the number of systems that need to be torn down in order to fulfill the piece part demand.

$$SystemsNeededToFulfillDemand_{x,y} = \frac{PartDemand_x}{GoodAttachRate_{x,y}}$$

- Each part is then sorted into ascending order based on the total number of systems needed to fulfill demand. By putting the parts in the order of systems needed to fulfill demand, the planner can understand how the recovery curve decreases as more and more systems are torn down. Put another way, if:

$$Rank_{x1,y} < Rank_{x2,y}$$

then:

$$SystemsNeededToFulfillDemand_{x1,y} < SystemsNeededToFulfillDemand_{x2,y}$$

Here a rank of 1 is defined as less than a rank of 2.

A new function $PartWithRank_i$ is also defined. It returns the part x with rank i.

- To calculate the recovery curve, SORT begins with the value of the initial torn down system ($FullValueTeardown_y$). As more systems are torn down, the value of each successive torn down system decreases since the subsequent parts are not needed to fulfill internal Dell parts demand and are being sold-as-is to a 3rd party. The amount the value of the torn down system declines by is $AveragePartRecoveryValue_{x,y}$. Thus, the formula for calculating the marginal value of each torn down machine is:

$$MarginalValueSystem_{x,y} = FullValueTeardown_y - \sum_{i=0}^{Rank_x} AveragePartRecoveryValue_{PartWithRank_i,y}$$

- At this point, SORT can calculate the marginal recovery curve using a scatter plot. The x-values are $SystemsNeededToFulfillDemand_{x,y}$, and the y-values are $MarginalValueSystem_{x,y}$. When plotted against one another, the resulting curve represents the estimated value of each incremental torn down system.
- A horizontal line representing the historical direct sale net recovery of Misburn systems is added to the chart.

The intersection point between the teardown curve and the Misburn direct sale line represents the optimal teardown target (similar to Figure 5). Fundamentally, this represents the optimal number of systems to send to teardown.

Output

Outputs	
	Dog
Total systems	13,108
Total EMR systems	3,109
Total Misburn systems	1,561
EMR population: teardown until	**123**
% incoming	*1%*
% EMR to teardown	*4%*
Misburn population: teardown until	**273**
% incoming	*2%*
% misburns to teardown	*17%*

Figure 18: Summary output report in SORT

The key output is the percentage of Misburn systems to send to teardown. Recall that Misburn systems tend to have lower direct sale net recoveries. In Figure 18, a sample summary output is provided. Here, SORT informs the planner that 17% of Misburn systems should be sent to teardown in the next month. By inputting this figure into MSS2, overall net recovery can be expected to be maximized.

4.3. Evaluation of savings through SORT

Estimating the value of SORT is challenging, as there is no true baseline to compare it against. Conceptually, there are two sources of savings through teardown. First, is the savings from sending systems through to teardown. Second is the savings from using SORT to send the *optimal* number of system to teardown. This is illustrated conceptually in Figure 19.

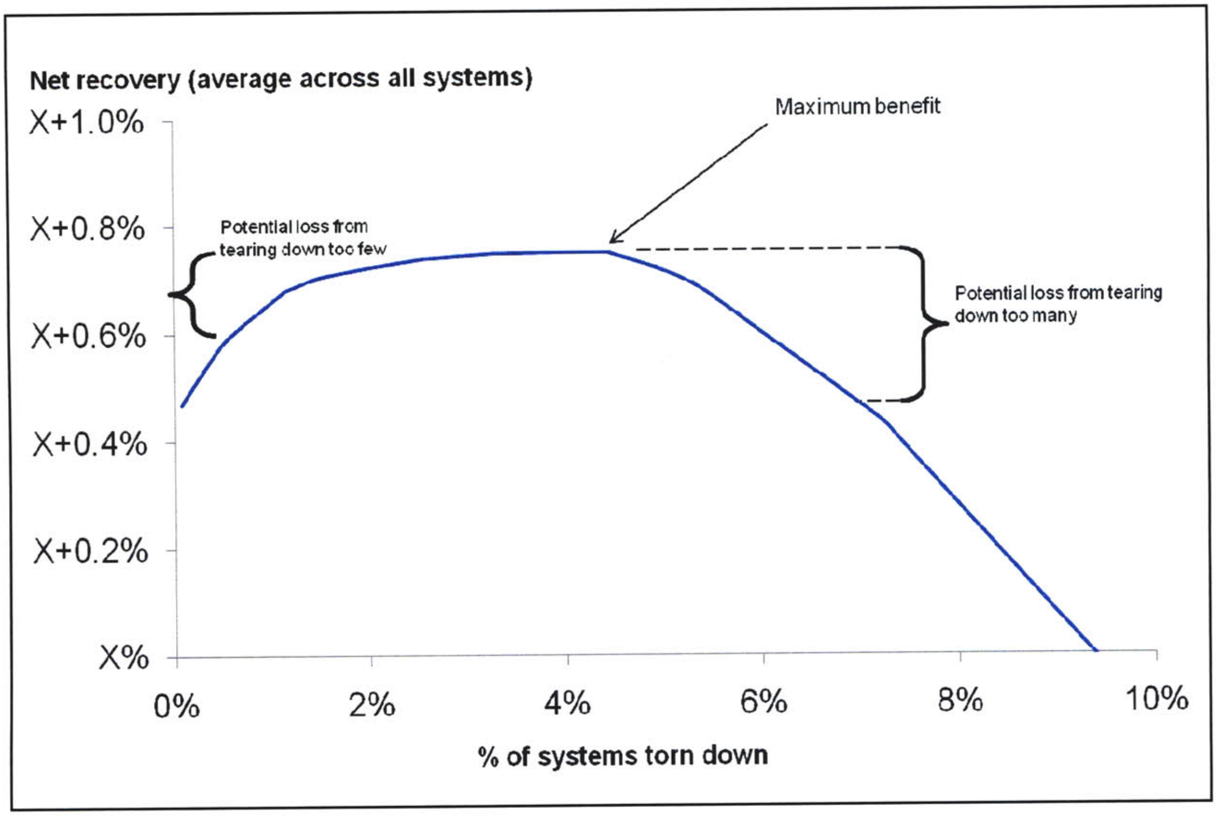

Figure 19: Calculating value of correctly setting number to teardown

Figure 19 shows the overall net recovery of a single product family based on the percentage of systems torn down. Tearing down 0% of system is equivalent to Dell's current state – namely, all systems are sold through direct sale. Where the line intersects with the y-axis is Dell's baseline net recovery. The value of teardown is simply the difference in net recovery between the baseline net recovery (when 0% of systems are torn down), and the net recovery when systems are torn down. The percentage of systems torn down can be set by a human planner by gut intuition, or can be aided with SORT. The value of the SORT decision system is the difference between human intuition and SORT's guided answer of how many to teardown. SORT's answer for how many systems to tear down should be the maximum point of the curve. In this illustrative example, the maximum overall net recovery is achieved by tearing down slightly more than 4% of returned systems.

It is difficult to estimate the true value of SORT due to the lack of a pre-existing system; SORT was developed to be the baseline. However, estimates can be made to evaluate potential savings. For example, if the percentage of systems sent to teardown were "incorrect" by 2%, then it would affect the overall net recovery by approximately 0.5% (in the illustrative example). Applied to an approximate figure of $500M in returned product per year, this equates to ~$2.5M improvement in EBIT for Dell[1].

[1] The value of returned product is disguised, but represents a directionally correct magnitude of returns at Dell at the time of the project.

5. Conclusions

This paper presents SORT, a new decision system for optimally routing returned computer systems to two potential recovery channels. This decision system is implemented with minimal IT investment, and is projected to improve Dell's net recovery (and bottom line) in excess of $1M per year.

5.1. Applications to other businesses and industries

This work should be relevant to any business that must make decisions about optimal recovery channel choices in the reverse supply chain. Specifically, SORT is applicable to channel decisions where the option set includes refurbishment/resale and piece part cannibalization. The model of predicting net recovery through teardown, based on the demand and value of individual piece parts will likely be valuable to many companies, assuming a relatively high volume, low piece part price, and an available market for functioning piece parts.

5.2. Potential further work

Value of gathering more information (system diagnosis test)

As seen in the analysis demonstrating that Misburns have lower net recoveries than systems originally dispositioned for EMR, return reasons often provide inaccurate information. System diagnostics can inform whether returned machines should be sent to EMR or Burn. Currently, this system diagnostics test is performed after Burn. It would likely be very valuable to change the process such that systems are tested upon receipt, and then routed after receipt.

Value of real-time system

General approach

The previous model does not incorporate system-level BOM information as it is received (i.e. what specific parts are in each received system). BOM information is available in the data systems, and should be used to ensure a more accurate matching of BOM to actual demand by parts.

Incorporating BOM information on a system-by-system basis would allow for a more accurate calculation of estimated net recovery through teardown. In the current SORT implementation, each BOM is treated as an “average” across all in the product family. Additionally, a linear regression of system properties against net recovery is created. By applying each individual system’s attributes through the regression, a system-specific estimated net recovery through resale can be generated and compared against the net recovery through teardown.

Close coordination between piece part customers and suppliers is vital

One of the more significant challenges in developing a new recovery channel based on parts is the new required capabilities in parts management. As systems become increasingly torn down for parts, the reverse supply chain will have to learn the capabilities of dealing with a massive parts inventory. Increasing IT, personnel, and financial coordination between piece part suppliers and customers will be very valuable in managing the risk of higher parts inventory.

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Glossary

ARB – Asset Recovery Business. Business unit of Dell responsible for handling returned product.

Burn – A station in the refurbishment process. Computers are formatted with a new software image, and tested.

COGS – Cost of Goods Sold. The original value of the returned computer system.

Direct sale – Currently Dell's primary recovery channel. Returned goods are sold to consumers on the Dell Outlet website.

EMR - Electromechanical Repair. A station in the refurbishment process. Returned computers with a hardware problem are sent here for repair by a Dell technician.

Family – A single product line.

Misburn – A returned system that was originally reported as having no hardware problem, but failed the system test in the Burn station.

Net Recovery Percentage – Sales recovery less operating expenses, as a percentage of COGS.

OPEX – Operating expenses, including labor and piece part consumption.

Sales Recovery Percentage – The amount returned product was sold for, as a percentage of the COGS.

Teardown – A recovery channel where returned systems are torn down for the piece parts.